Fast Flow in Unsaturated Coarse Sediments

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RESEARCH OBJECTIVES

Unsaturated flow in very coarse sediments is a critical area for improving our understanding of vadose zone flow and transport. In particular, very coarse-textured (>1 mm grain-size) media can sustain high flow rates at relatively low saturations, doing so via film flow rather than by flow through an interconnected network of saturated pores. Thus, the physics of fast flow processes in unsaturated very coarse media is fundamentally different from that traditionally recognized in finer textured sediments. Our general objectives are (1) to quantify the macroscopic hydraulic properties of very coarse textured sediments in the near-zero (-10 to 0 kPa) matric potential region, and (2) determine the microscale basis for fast unsaturated flow. Through these studies, we will develop appropriate scaling relations for unsaturated flow in coarse-granular sediments.

APPROACH

Reconciling macroscopic (column) and microscopic (grains, pores, films) aspects of unsaturated flow requires direct, quantitative measurements at both scales. Therefore, studies are being conducted to quantify macroscopic and microscopic hydraulic properties and processes in coarse sands and gravels. We are focusing most of our efforts on sediments from the Hanford Site (Hanford formation, grain-sizes ranging from 0.1 to 50 mm). This is a difficult energy region to study because of extreme changes in saturation and conductance that take place in coarser textured media. Three methods for obtaining bulk measurements of unsaturated potential-saturation-conductance have been modified to obtain these measurements: suction-plate equilibration, unit gradient infiltration, and steady evaporation.

For microscale measurements of average film thickness, we employ a recently developed x-ray technique. These experiments build on our previous experience with film flow on roughened quartz glass surfaces. The method relies on determining average water film thicknesses using x-ray fluorescence of a solute tracer. A Hanford gravel sample is placed in a small suction plate device and scanned with a defocused synchrotron x-ray microbeam while equilibrating to selected matric potentials. These x-ray experiments are conducted at the National Synchrotron Light Source (Brookhaven National Laboratory). Experiments were conducted in the 0 to –10 kPa matric potential range, with most tests in the 0 to –2 kPa region, which permits fast film flow in larger, unsaturated pores.

ACCOMPLISHMENTS

The experiments on macroscopic hydraulic characteristics focus on the near-zero matric potential range where gravel pores are drained. This energy range was identified from capillary drainage calculations and from measured saturations. Under conditions of drained pores, the measured unsaturated hydraulic conductivity is film-controlled. Moisture characteristics (matric potential versus saturation), and unsaturated hydraulic conductivities are being obtained on Hanford formation gravels at the column scale. These hydraulic properties are being compared with grain-film hydraulic properties in order to explain macroscale flow and transport through tested microscale concepts. A new tensiometer has been developed to provide measurements of hydraulic potentials with high spatial (1.0 mm) and energy (10 Pa) resolution. The new high-resolution tensiometer also has a fast response time (<1 s) in the near-zero matric potential region. Initial experiments on film hydraulic properties have been completed, with results similar to those obtained in our previous work on transient film flow. Film moisture characteristics on gravel surfaces are practically non-hysteretic. Film hydraulic diffusivities appear to be monotonically decreasing functions of average film thickness.

SIGNIFICANCE OF FINDINGS

Our analyses of unsaturated flow in coarse sediments are showing that at near-zero matric potentials, fast film flow is possible. Magnitudes of fast, unsaturated flow in gravels at near-zero matric potentials are consistent with direct measurements of film hydraulic properties.

RELATED PUBLICATION

Tokunaga, T.K., J. Wan and S.R. Sutton, Transient film flow on rough fracture surfaces, Water Resour. Res., 36, in press, 2000.

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